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SELECTION OF CANDIDATE REFERENCE EVENTS IN THE NORTHERN CAUCASUS REGION

Final Report

V.V. Kirichenko, Yu.A. Kraev
Western Services Corporation, Accredited Representative Office
3, Skakovaya Street, Moscow, Russia, 125040

I.P. Gabsatarova, O.E. Starovoit
Geophysical Survey of the Russian Academy of Sciences
189, Lenin Avenue, Obninsk, Kaluga Region, Russia, 249020

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APPENDICES:

1.0 INTRODUCTION

The primary goal of this project is to select candidate calibration events among recent Northern Caucasus earthquakes (1994 – 2000) according to the Group 2 Consortium GT5 candidate events selection criteria. These criteria are as follows:

GT5 candidate event selection criteria at the 90% confidence level

- at least 10 stations within 250 km from the epicenter,
- maximum primary azimuthal gap <= 110 degrees at stations within 250 km,
- at least one station within 30 km.

GT5 candidate event selection criteria at the 95% confidence level

- at least 10 stations within 250 km from the epicenter,
- maximum primary azimuthal gap <= 110 degrees at stations within 250 km,
- maximum secondary azimuthal gap <= 160 degrees at stations within 250 km,
- at least one station within 30 km.

desirably in both cases:

- Pn/P phases recorded beyond 250 km,
- observed phases at IMS or surrogate IMS stations,
- magnitude, mb >= 3.5,
- depth <= 35 km,
- event located using a local velocity model.

As a starting point of the project performance the regional bulletins of the Geophysical Survey of the Russian Academy of Sciences for the Northern Caucasus region were used. At the stage of preliminary analysis 25 events in the NORTHWESTERN CAUCASUS region as well as 36 events in the EASTERN CAUCASUS region (Flinn, Engdahl, Hill,1974) were selected. Parameters of these events are presented in Table 1. Figure 1 illustrates a location of selected events.

As a result of our preliminary analysis (Kirichenko and Kraev, 2000) we concluded that candidate calibration events per the aforementioned Group 2 Consortium criteria can not be selected without adding new arrival data from seismic stations being operated as a part of Dagestan, Georgian and Azerbaijani regional seismic networks as well as carrying out an analysis of entire collected data sets.

According to the Statement of Work developed by the Group 2 Consortium we were requested to perform the following tasks:

1. Collection of all available data on arrival times for selected reference event candidates in the Northern Caucasus region.

2. Collection of local and regional velocity models and travel-time tables for Northern Caucasus.

3. Relocation tests on the selected reference event candidates using local and regional velocity models and both newly collected and currently available phase data. Identification of GT5 or better reference events based on the Group 2 Consortium GT5 reference event criteria.

Our team included researchers from Western Services Corporation (Accredited Representative Office in Moscow) and Geophysical Survey (GS) of the Russian Academy of Sciences (RAS).

Results of the project performance are presented below.

2.0 COLLECTION OF DATA ON ARRIVAL TIMES FOR SELECTED REFERENCE CANDIDATE EVENTS IN THE NORTHERN CAUCASUS REGION

For 61 selected potential reference events primary data on arrival times was taken from archives of the GS RAS. Additional data on arrival times for the same set of potential reference events was requested from stations of regional and local seismic networks in Dagestan, Georgia and Azerbaijan. Station site information on recording regional and local stations is presented in the Attachment I. This information was taken from the publications of Kondorskaya and Fedorova, 1996; Papalashvili and Chichinadze, 1999; Gasanov, 1999; Arakelyan and Sarksyan, 1999; Papalashvili et al., 1999; Daniyalov et al., 1999. Figure 2 illustrates the location of these local and regional stations.

Seismic records available in archives of the Georgian Regional Center were processed for all potential reference events. Seismic records processing was conducted on the basis of Levitskaya and Lebedeva regional travel time table (Levitskaya, Lebedeva, 1953). The most part of arrivals was named as ? and S only and was a subject of additional interpretation especially for secondary arrivals. Arrival times data from Georgian stations (provided as paper reports) was transformed to the electronic format of the HYPO-71 software for preliminary hypocenters determination.

Similar effort was performed with data from Azerbaijani stations.

MS Access database for this project performance was created in the CSS 3.0 format. The basic tables such as **origin, arrival, assoc, site, instrument, sitechan, affiliation, glossary** were used . Figure 3 illustrates the MS Access database structure. Collected station site information on recording stations and arrival times were included to the database. All collected arrival times were included in the table **arr_ev**. All collected data on arrival times is listed in the Appendix II for 61 selected candidate events.

3.0 COLLECTION OF LOCAL AND REGIONAL VELOCITY MODELS AND TRAVEL TIME TABLES FOR NORTHERN CAUCASUS REGION

Northern Caucasus territory is presented by different tectonic structures (Krylov, 1987): in the north – by the Ciscaucasia epihercynian platform and its elements: the Scythian plate, the Terek-Caspian depression and Indolo-Cuban foredeep; in the south – by the Caucasus mountain system with structurally different western, central and eastern sections. Inhomogeneity of the Earth's crust structure for the studied region is presented by the variability of seismic wave velocities as well as by different layer's thinknesses (Krasnopevtseva, 1984; Levitskaya and Lebedeva, 1953; Pivovarova and Slavina, 1985; Murusidze, 1976; Alexidze, 1983; Asmanov, 1980). Basic data on the deep structure of the Caucasus region may be found in the book of Krasnopevtseva, 1984. This data is based on the results of DSS, seismic survey and other geophysical fields studies. Figure 4 presents the velocity models of the Earth's crust for the Caucasus region (Krasnopevtseva, 1984). Table 2 summarizes the same information in the table format.

During a long period of time the travel-time tables of Levitskaya and Lebedeva, constructed for event depths in the range from 0 to 25 km, had been used in the practice of epicenter determinations in the Northern Caucasus region and Georgia (Levitskaya and Lebedeva,1953). This travel-time table is presented in the Attachment III as well as illustrated by the figure 5. The most serious limitation for this travel-time table is its generalization for the depths in the interval from 0 to 25 km. As a result these travel-time tables are practically useless for accurate hypocenter determinations.

At the present time, developed in 1984-1988 methods are being used for hypocenter determinations. These methods are based on use of the Earth's crust velocity models as well as so called area related travel-time tables (Pivovarova and Slavina, 1985; , Alexidze, 1983; Zakharova and Gabsatarova, 1993). Pivovarova and Slavina, 1985, developed the procedure for hypocenter determinations taking into account the block structure of the Caucasus region. The Caucasus region was subdivided into six blocks with different Earth's crust models (Figures 6(a) and (b)). The paper of Pivovarova and Slavina, 1985, contains these area related travel-time tables constructed for various relative locations of station-event pairs. These tables were constructed for the distances range from o to 300 km on the basis of 3-D block structure model for the Caucasus region. Regionalization of the Caucasus region is shown in the figure 6(a) by dashed lines. This regionalization is based on the results of DSS studies.

The paper of Pivovarova and Slavina, 1986, also contains the generalized 1-D travel-time table for entire Caucasus region constructed for the distances range from 0 to 450 km. Attachment III presents Pivovarova&Slavina travel-time tables for different depths of events (from 0 to 40 km with increment of 10 km) and various relative locations of event-station pairs. Above the distance of 300 km these travel-time tables are added by the generalized 1-D travel-time table for the entire Caucasus region.

After the catastrophic Dagestan earthquake as of May 18, 1970, the network of temporary, regional and local seismic stations had been operational during the time frame of 1970 – 1977. Observational data of these stations provided an opportunity to construct reliable local travel-time tables of direct P and S waves for the distance interval of 3 – 70 km and the depth interval of 3 – 24 km. These travel-time tables in the LocSat format are presented in the Attachment III. Practical applications of these travel-time tables for hypocenter determinations at the territory of Dagestan wedge allowed to conclude on good coincidence with results based on the Vadati method. The paper of Asmanov, 1980, recommends to use these travel-time tables for hypocenter determinations with regard to other Dagestan regions with similar Earth's crust structures. Table 3 presents data on average velocities for different depths of events within the Dagestan wedge.

The HYPO-71 software and corresponding velocity models are being used for earthquake catalogues composition with regard to the Northern Caucasus region. The complexity of the Earth's crust structure for this region does not allow to use the only velocity model for the entire region. After an analysis of available velocity models (based on DSS and seismic surveys) for the subject region it was concluded that the territory of the Northern Caucasus may be subdivided into four zones (Zakharova and Gabsatarova, 1993): **A** – western zone (Indolo-Kuban foredeep and western spurs of the Greater Caucasus), **B** – central zone (Ciscaucasia central block) and two eastern zones: **C** –Terek-Caspian depression and **D** – eastern spurs of the Greater Caucasus. The corresponding velocity models are taken from the publications of Krylov, 1987; Murusidze, 1976; Fyatelson, 1982, and are presented in Table 4.

3.1 Comparative Analysis of P-Waves Regional Travel-Time Tables for the Caucasus Region

Pivovarova and Slavina, 1985, did compare their travel-time tables with the travel-time tables of Levitskaya and Lebedeva, 1953, as well as with the Jeffreys-Bullen travel-time tables for the regional zone and concluded the following. In the range of epicentral distances from 0 to 10 km, the differences between the various travel-time tables for the depths (h) of 0, 10, 20, 30 and 40 km, are about 2 sec for the 1-D modeling approach and about 1 sec for the 3-D modeling approach. This fact allows to differentiate event depths in the process of hypocenter determinations. However, if an accuracy of arrival times is from 0.5 to 1 sec, calculated event depths may be a subject of substantial errors.

The most unreliable distance range is from 20 to 40 km where all the noted above reduced travel-time tables are undistinguished in the interval from 0.5 to 0.8 sec.

If a closest station is located in the range from 40 to 120 km, the use of 1-D based travel-time tables provides higher depth estimates as compared to 3-D based travel-time tables. In the range of 120 to 250 km, travel-time tables for the depths of 0 and 20 km are obviously different for any modeling approaches. Pivovarova and Slavina, 1985, noted that the velocity structure of the block IV (Lesser Caucasus) is characterized by higher velocities as compared to the 1-D block model for Caucasus. The same fact is highlighted by Krasnopevtseva, 1985: the velocity model for the Sevan Ophilite belt of the Lesser Caucasus is characterized by the most high velocities for the entire Caucasus region.

In general, Pivovarova and Slavina concluded that Lebedeva and Levitskaya travel-time tables at the distances from 20 to 100 km are similar to their 1-D travel-time table for the h=20 km, and for the distances higher 130 km are close to their travel-time table for the h=0 km.

The above analysis of generalized P travel-time tables of Pivovarova and Slavina, 1984, and Krasnopevtseva, 1985, for the entire Caucasus region (generalized for sources in the Earth's crust) allows to conclude that the travel-time table of Krasnopevtseva and the travel-tame table of Pivovarova and Slavina for the h=10 km are in good agreement (see Figure 7). It is worth to note that most of Caucasus's earthquakes are at the depths from 5 to 10 km.

We also did compare travel-time tables constructed for the specific regions. Figure 8 presents a comparison of the travel-time tables developed by Pivovarova and Slavina for the region II (southern part of the Scythian plate and Terek-Caspian depression) and the travel-time tables of Krasnopevtseva for the Scythian plate and the Terek-Caspian depression. Travel-time tables of Krasnopevtseva for both provinces are in good agreement: differences between tables are from 0.3 sec to 0.8 sec, reaching 1.6 sec for the distance of 300 km. Also, they are in good correspondence with the Pivovarova and Slavina travel-time table for the h=0 km.

A similar comparison was done for the zone III of Pivovarova and Slavina (different event depths) and travel-time table of Krasnopevtseva for Greater Caucasus (see Figure 9).

At the distance of 10 km the travel-time table of Krasnopevtseva is coincided with the travel-time table of Pivovarova and Slavina for the h=10 km. At the distance of 50 km – with the travel-time table of Pivovarova and Slavina for the h=40 km. At the range from 100 to 200 km – with the travel-time table of Pivovarova and Slavina for the h=0 km.

The above results of comparison of the travel-time tables developed by different authors, allowed us to recommend the travel-time tables of Pivovariva and Slavina as basic tables for our relocation studies and selection of candidate reference events. The most important reasons for our choice are obvious: 1) the travel-time tables of Pivovarova and Slavina are developed for tectonically different provinces of the Caucasus region; 2) these tables are available for different source depths (0 km, 10 km, 20 km, 30 km and 40 km); 3) these travel-time table are in good/satisfactory agreement with the travel-time tables of Krasnopevtseva which are based on DSS surveys.

Studied in the framework of our project earthquakes are located within the central part of the zone **B** and within the eastern part of the zone **C** per Zakharova and Gabsatarova, 1993. The Earth's crust models which are used in the practice of hypocenter determinations of Northern Caucasus sources by the HYPO-71 software were used for travel-time tables calculations. These calculated travel-time tables were compared with travel-time tables developed by other researchers. The travel-time tables for Dagestan events (zone **C**) are available from the paper of Asmanov,1980. Figures 7 and 8 illustrate a comparison of different reduced travel-time tables for the distances up to 120 km and events depths as of 0 km and 10 km. We may conclude that the travel-time table of Faytelson, 1982, developed for the central part of the Ciscaucasia and Pg IASPEI-91 travel-time tables for the depth of 0 km (Figure 10) and the depth of 10 km (Figure 11) are in a good agreement.

3.2 Comparison of IASPEI-91 P Travel-Time Tables with Regional Travel-Time Tables for Caucasus Region

Figures 9 and 10 presents a comparison for the distances from 0 to 120 km of the IASPEI-91 Pg travel-time curves and travel-time curves of Pivovarova and Slavina, 1985, developed for the relative locations of source-station pairs within the block II (southern part of the Scythian Plate and

Terek-Caspian depression) and within the block III (Greater Caucasus). These relative source-station pairs locations are most typical for our project studies.

As we may see from the Figure 9 for the region II the most differences take place for surface sources (black continuous and dashed lines): from about 2 sec at the distances 0-10 km and to about 3.5 sec at the distances 70 – 120 km. In general, the IASPEI-91 travel-time tables are more high-velocity as compared to the Pivovarova and Slavina travel-time tables for surface events. However, for events depth of 10 km (yellow lines) the differences are from 0 to 1.5 sec only; also, Pivovarova and Slavina travel-time curve for h=30 km and the IASPEI-91 travel-time curve for h=35 km are very close.

For the region III the most differences also as above take place for surface sources (black continuous and dashed lines), but the values of these differences are lower: about 1 sec for distances from 0 to 10 km and about 3.0 sec for distances from 70 to 120 km. In general, the IASPEI-91 travel-time tables are more high-velocity as compared to the Pivovarova and Slavina travel-time tables for surface events.

3.3 Recommendations on Use of Travel-time Tables for Hypocenter Determinations in the Northern Caucasus Region

1. It is recommended to use Pivovarova and Slavina travel-time tables as basic tables for hypocenter determinations in the Northern Caucasus region. The advantages of these travel-time tables are as follows. They take into account relative location of event-station pairs in the same or different tectonic blocks. They were developed for different (0 km, 10 km, 20 km, 30 km and 40 km) event depths. These travel-time tables are detailed, and the total amount of specific travel-time tables is 180.
2. To improve a reliability of depth determinations it is recommended to use for closest stations (in the range from 0 to 20 km) the local Dagestan travel-time table for the sources within the eastern zone and the travel-time table of Faytelson, 1982, for the sources in the central zone (above latitude 44 deg. N). Also, it may be proposed to use IASPEI-91 Pg travel-time tables based on the comparison results presented above.
3. It is proposed to calculate S travel-time tables based on P travel-time tables (Vp/Vs velocities ratio 1.73) or to use IASPEI-91 S travel-time tables.
4. The travel-time table for the first Lg wave arrivals constructed by Pataraya, 1964, for the distances from 200 to 1500 km is in a good agreement with IASPEI-91 Lg travel-time tables (see Figure 11). Thus, we recommend to use IASPEI-91 Lg travel-time tables.

4.0 RELOCATION TESTS AND RESULTS OF REFERENCE EVENTS SELECTION

Relocation tests were performed in two stages.

In the first stage all candidate reference events from the Table 1 were relocated using regional travel-time tables and all collected data on arrival times. Estimates of latitude, longitude and origin time for all candidate events are presented in the Attachment II. As a result, 19 candidate events were selected for further tests.

In the second stage the aforementioned 19 candidate events were studied taking into account the Group 2 Consortium GT5 selection criteria at the 90% and 95% confidence levels. We did follow the recommendation of Istvan Bondar on the limitation of epicentral distances as of 300 km for final hypocenter determinations. After that the selection criteria was applied. The results of our selection process are presented in Tables 5.1, 5.2 and 5.3 for three groups of events which: a) satisfy the 90% and 95% confidence level criteria; b) close to the criteria discrimination parameters and c) are examples of other studied events.

Attachment IV contains bulletins in the IMS 1.0 format for the 19 aforementioned events.

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FIGURES

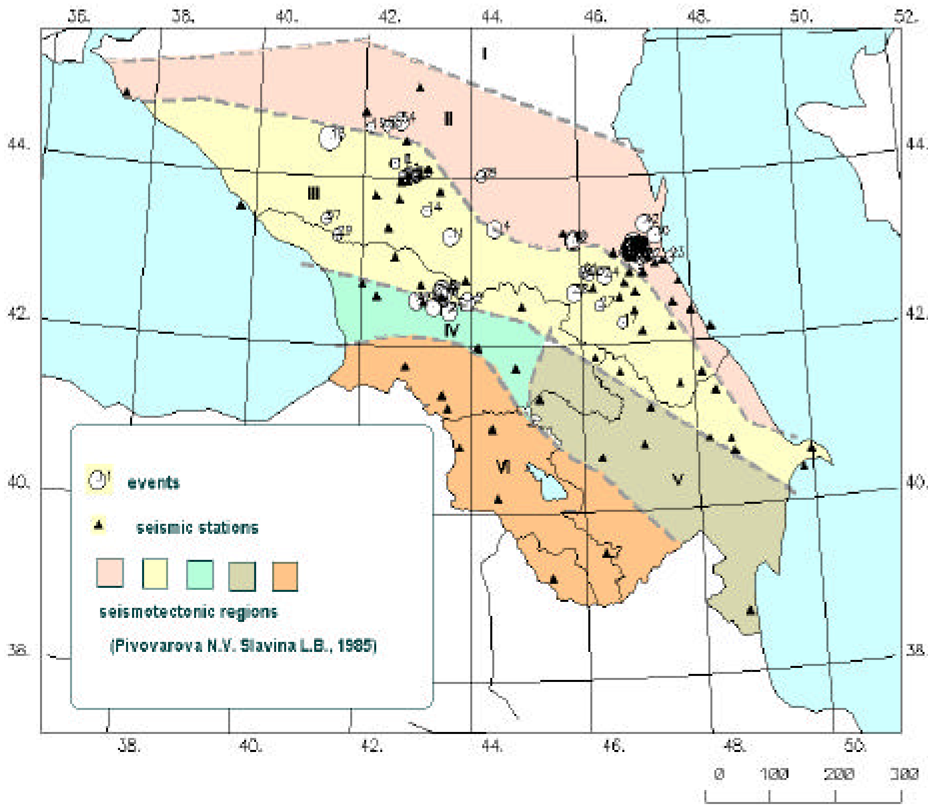


Figure 1. Location of Candidate Reference Events.

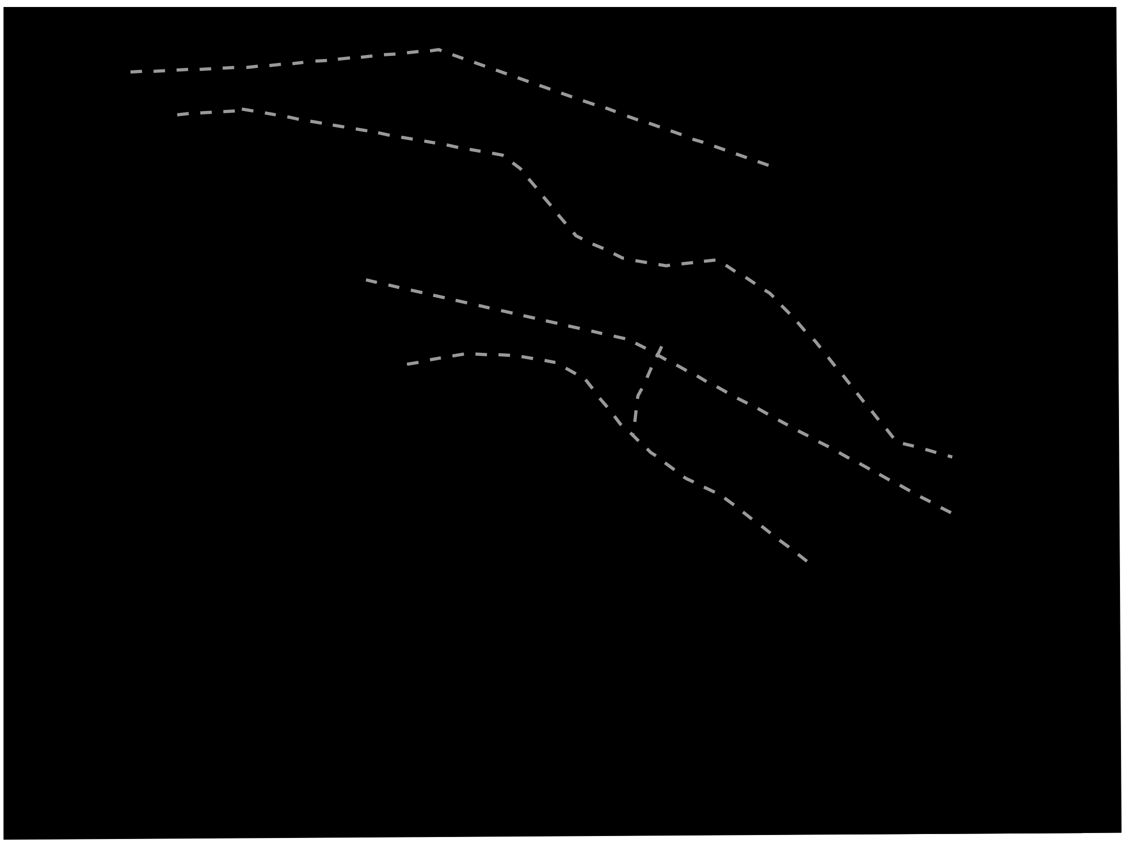


Figure 2. Location of regional and local stations of the GS RAS, Dagestan, Georgia and Azerbaijan seismic networks. The gray lines are borders of distinct seismotectonic zones with different Earth crust models (Pivovarova, Slavina,1985).

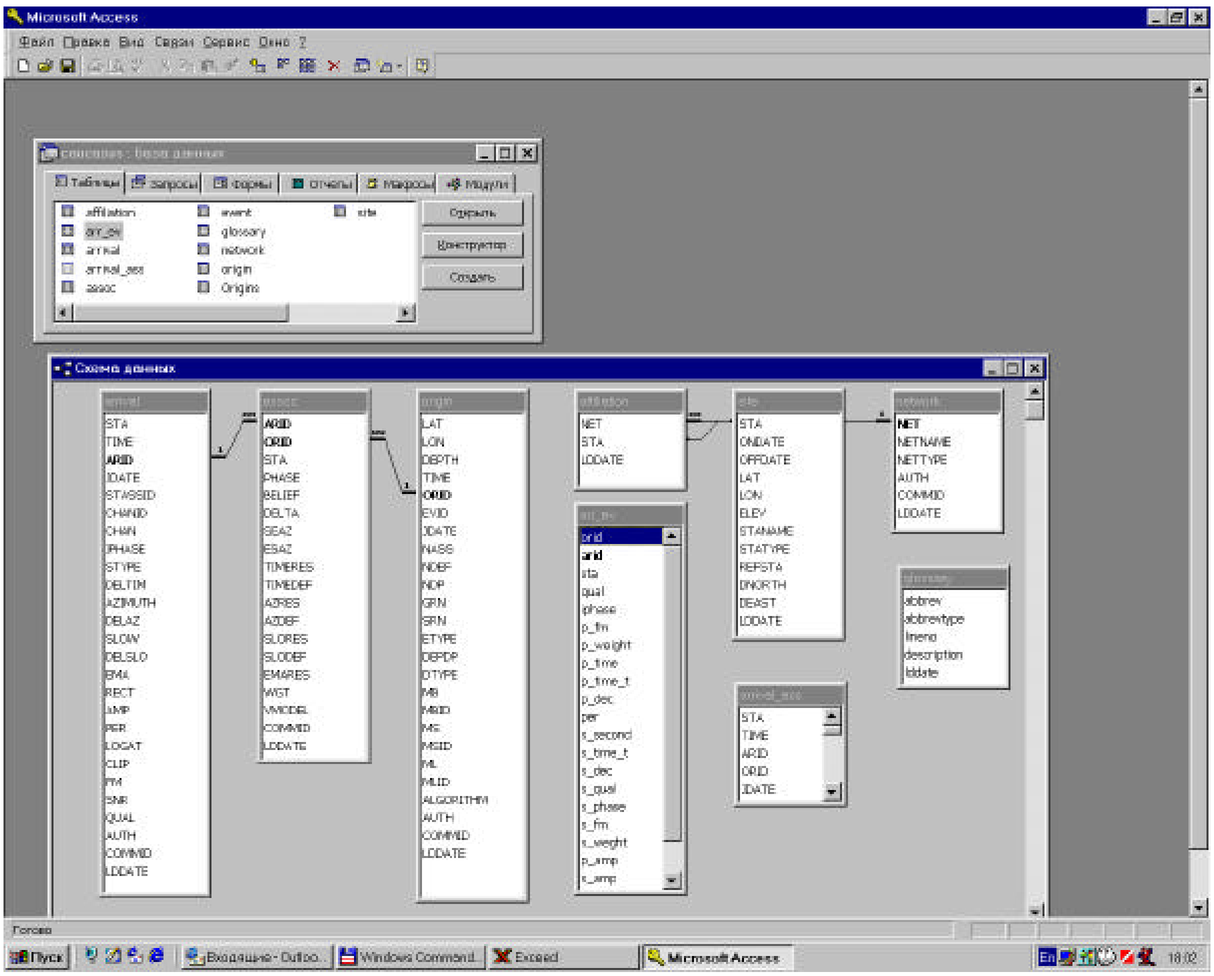


Figure 3. MS Access Database Structure for Selected Candidate Events in the Northern Caucasus Region.

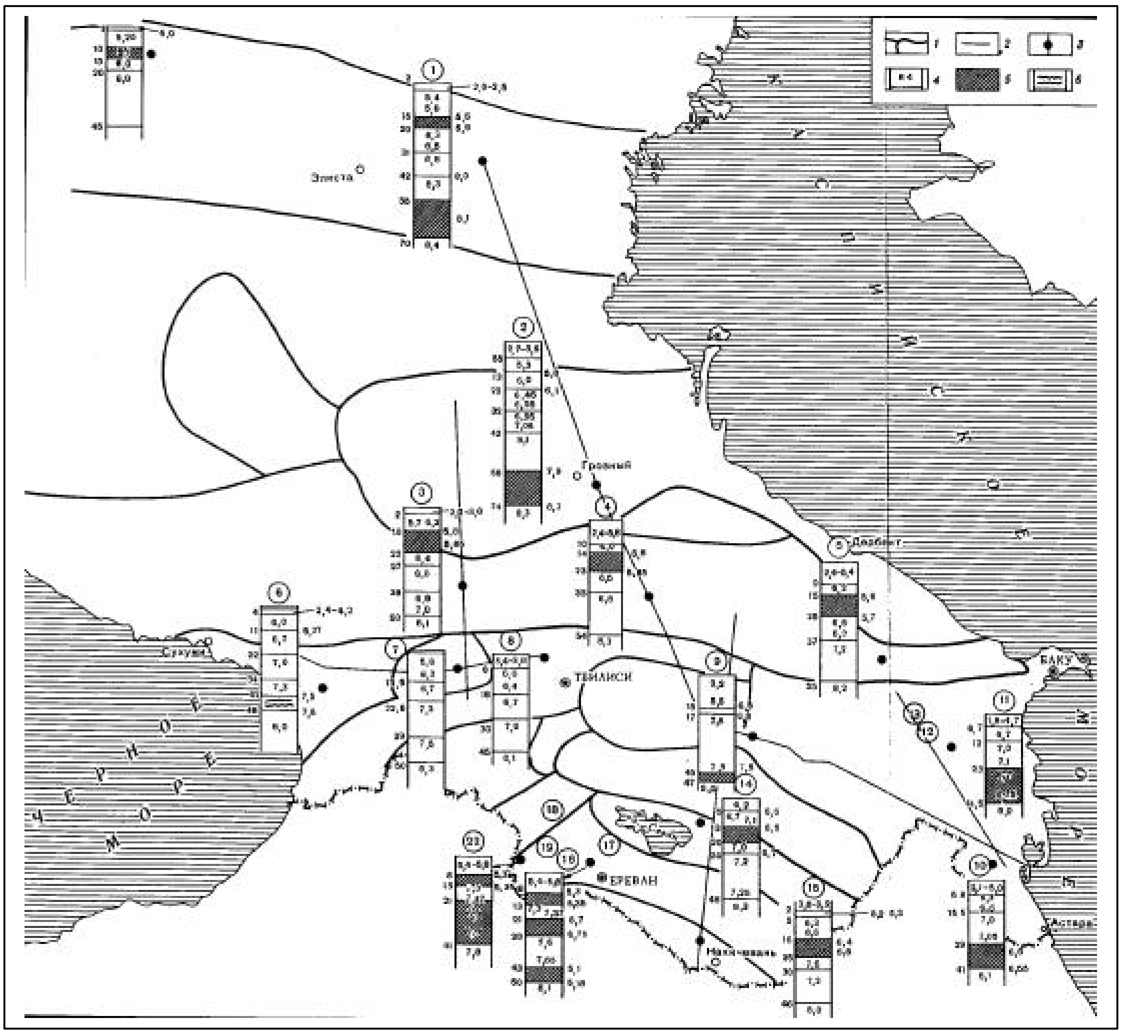


Figure 4. Regionalization of the Caucasus region by the types of the Earth's crust (Krasnopevtseva, 1984). Explanations: 1- block boundaries; 2 – DSS profiles; 3 – DSS section to which a model is related; 4 – values of layer's velocities; 5 – low-velocity zone; 6 – high-velocity zone.

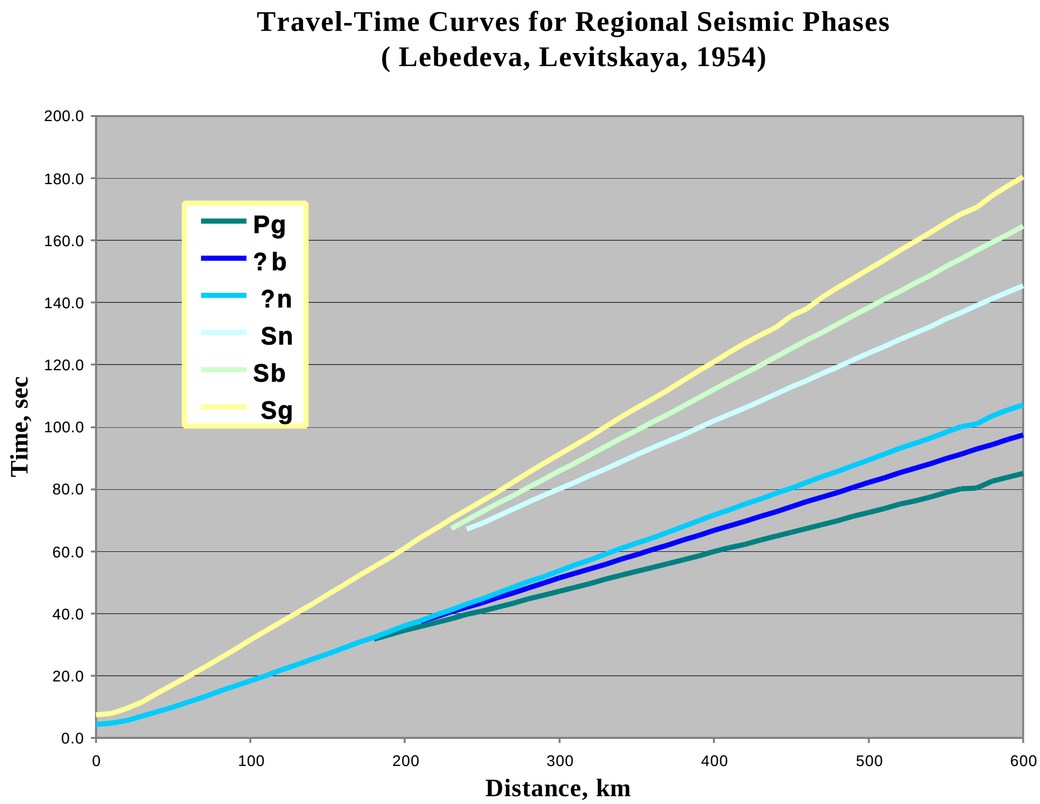
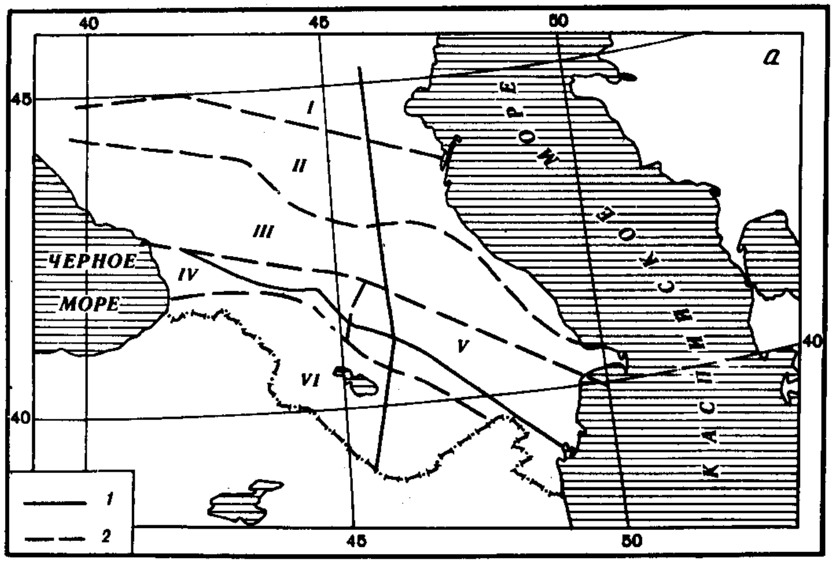
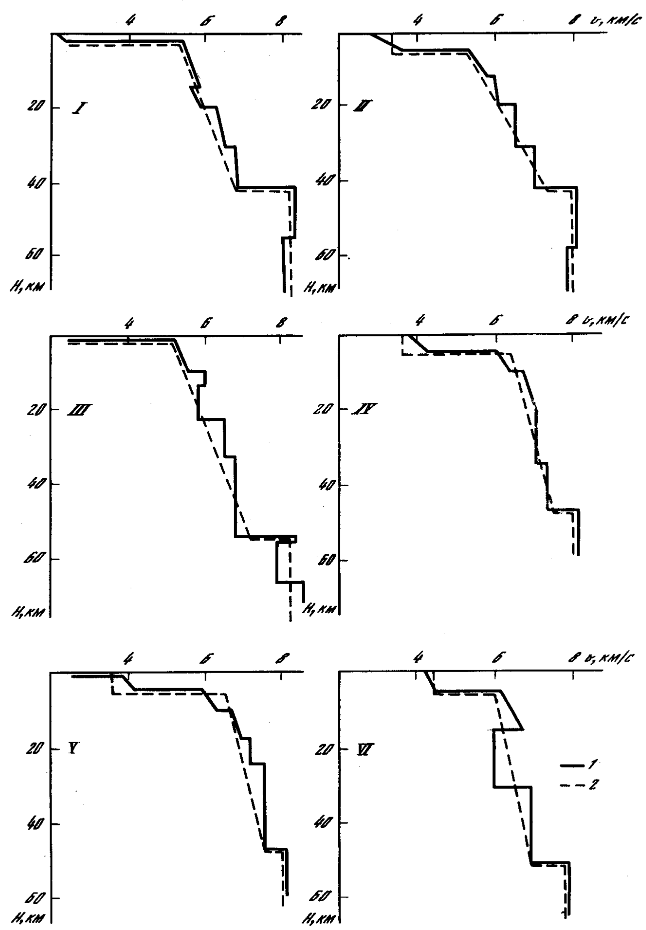


Figure 5. Travel-Time Curves for Regional Seismic Phases for the Caucasus Region (Lebedeva and Levitskaya, 1953).



(a)



(b)

Figure 6. Regionalization of the Caucasus Region on the Specific Blocks (a) and the Corresponding Earth’s Crust Velocity Models (b).Explanations: continuos lines are 3-D Earth’s crust and upper mantle structure; dashed lines are approximations of the 3-D structures by three-layer models for event location studies.

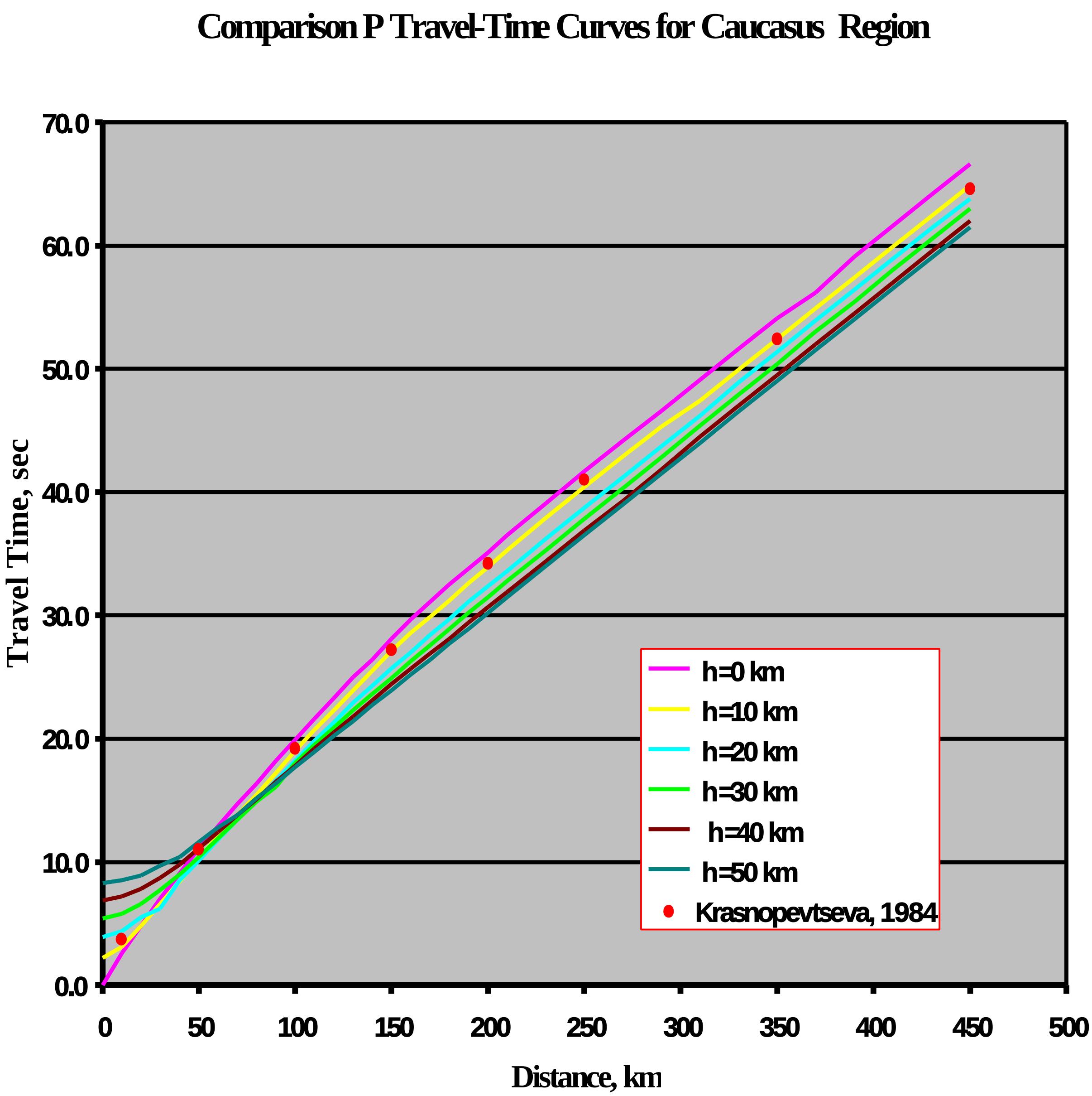


Figure 7. Comparison of Generalized P Travel-Time Tables of Pivovarova&Slavina, 1985, and Krasnopevtseva, 1984, for the entire Caucasus region. Travel-time tables of Pivovarova&Slavina are shown by color lines and the travel-time table of Krasnopevtseva is shown by red dots.

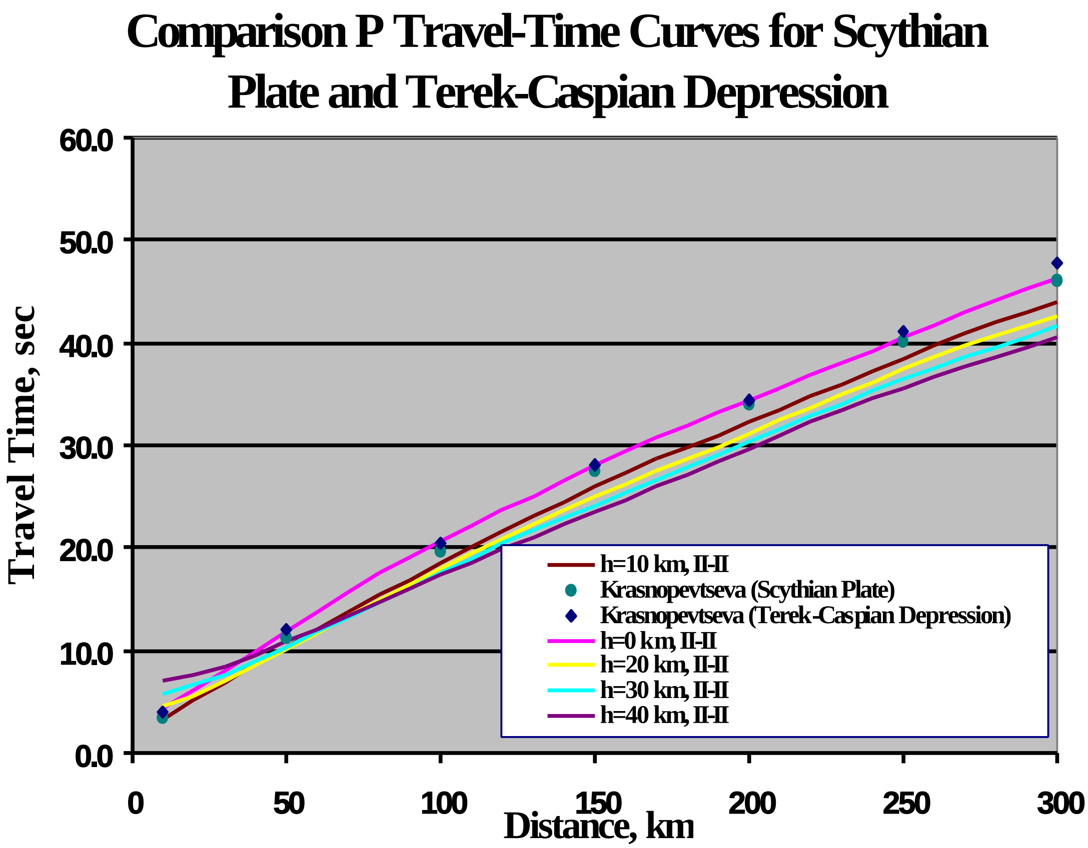


Figure 8. Comparison of P Travel-Time Tables for Scythian Plate and Terek-Caspian Depression.

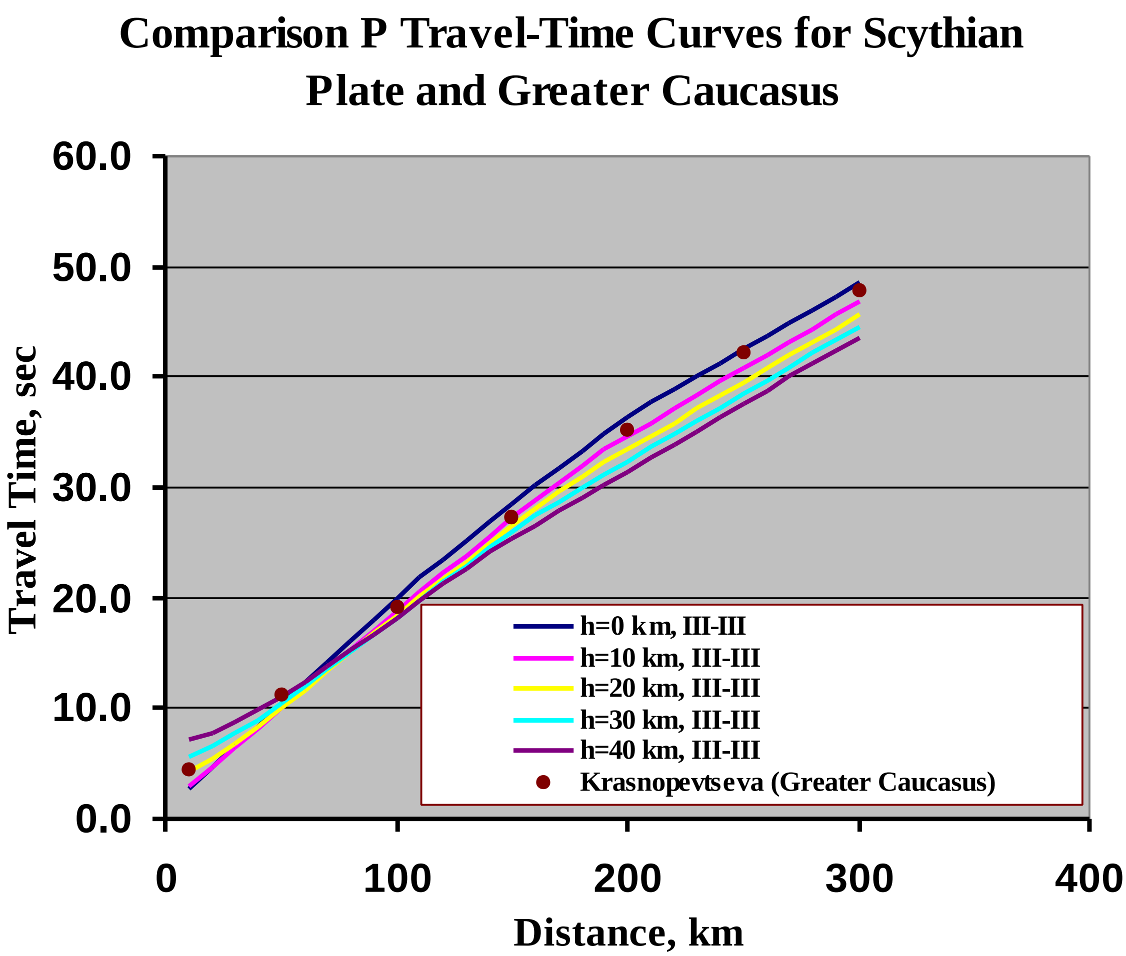


Figure 9. Comparison of P Travel-Time Tables for Greater Caucasus.

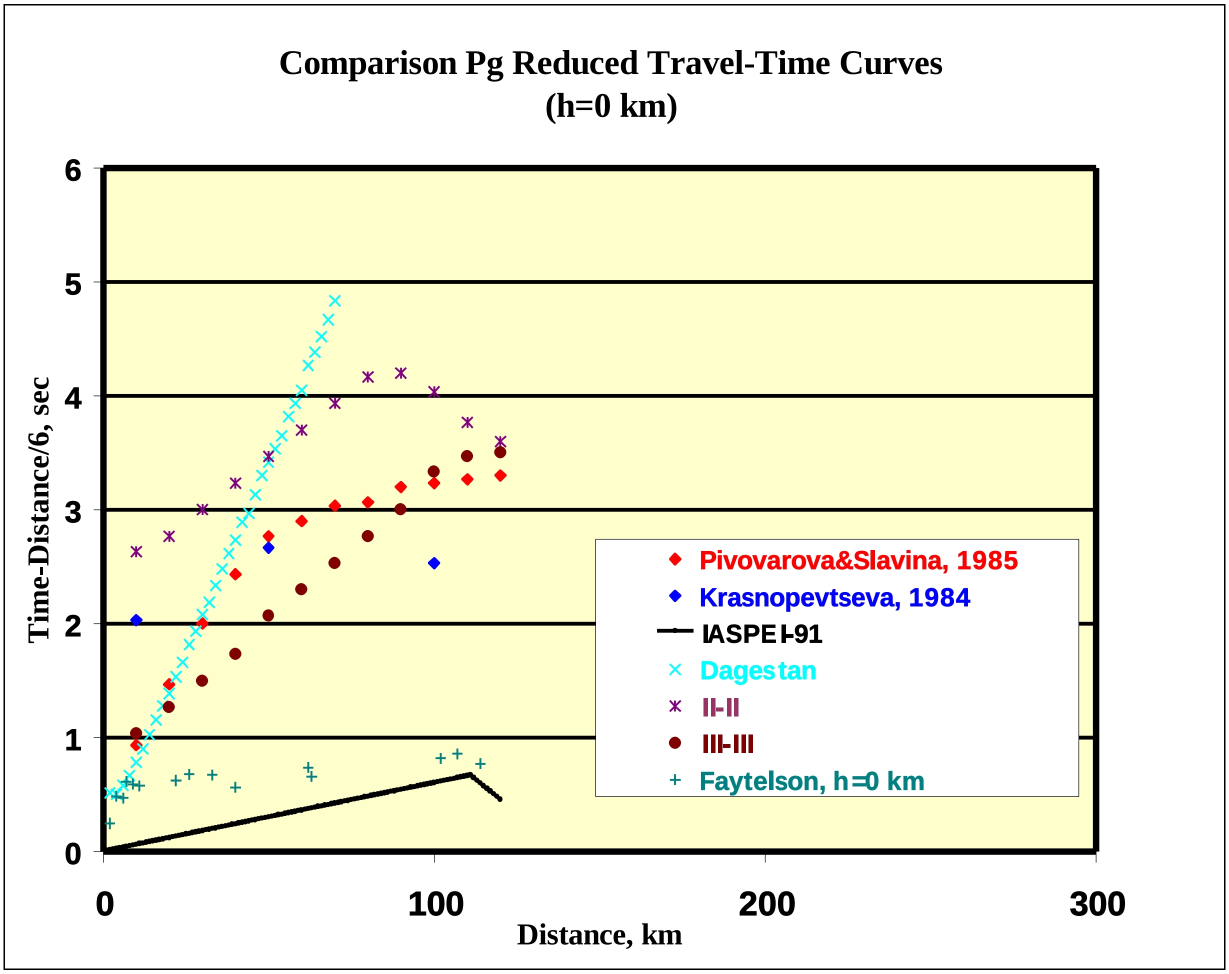


Figure 10. Comparison of Pg Reduced Travel-Time Tables (h=0 km).

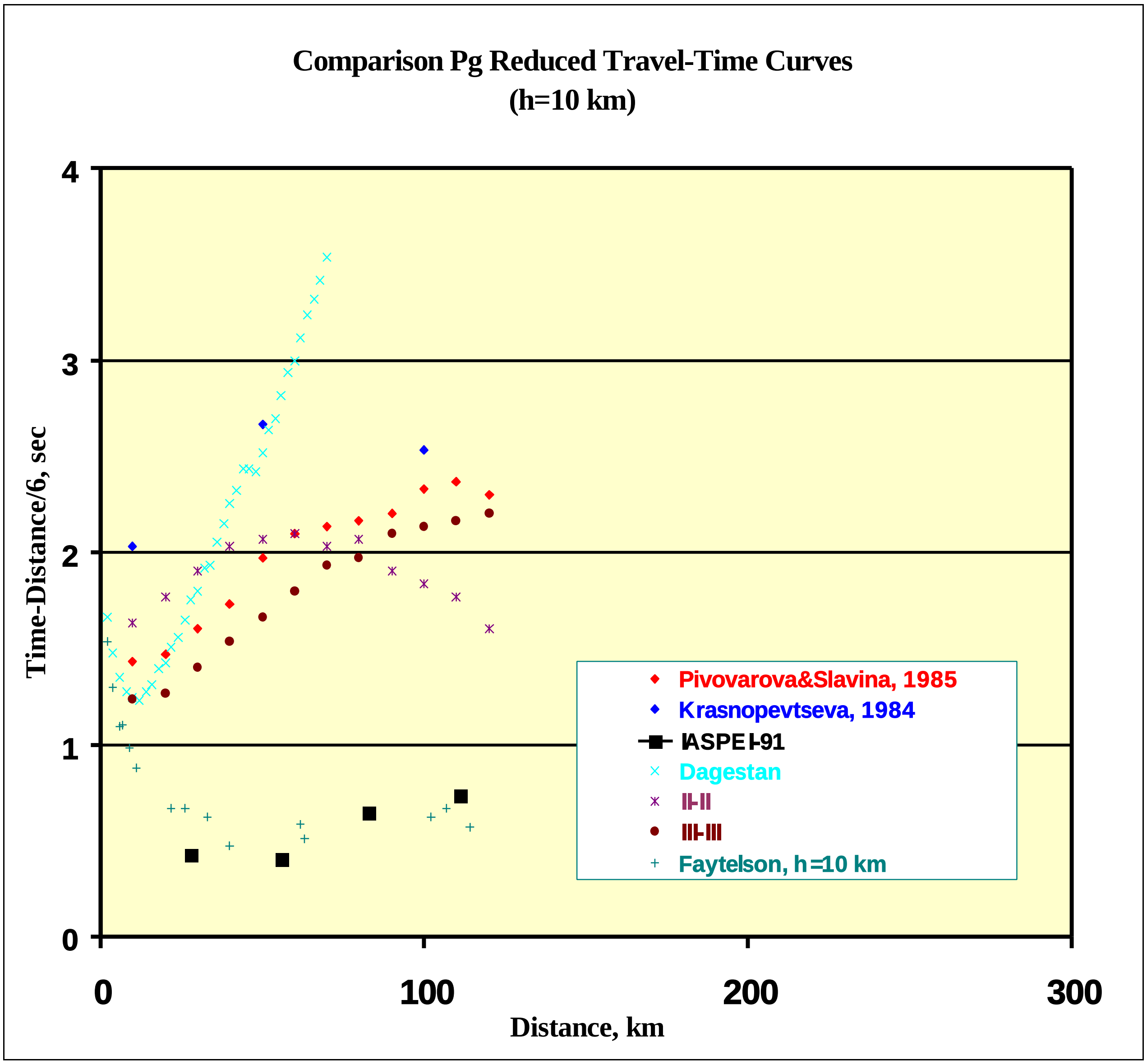


Figure 11. Comparison of Pg Reduced Travel-Time Tables (h=10 km).

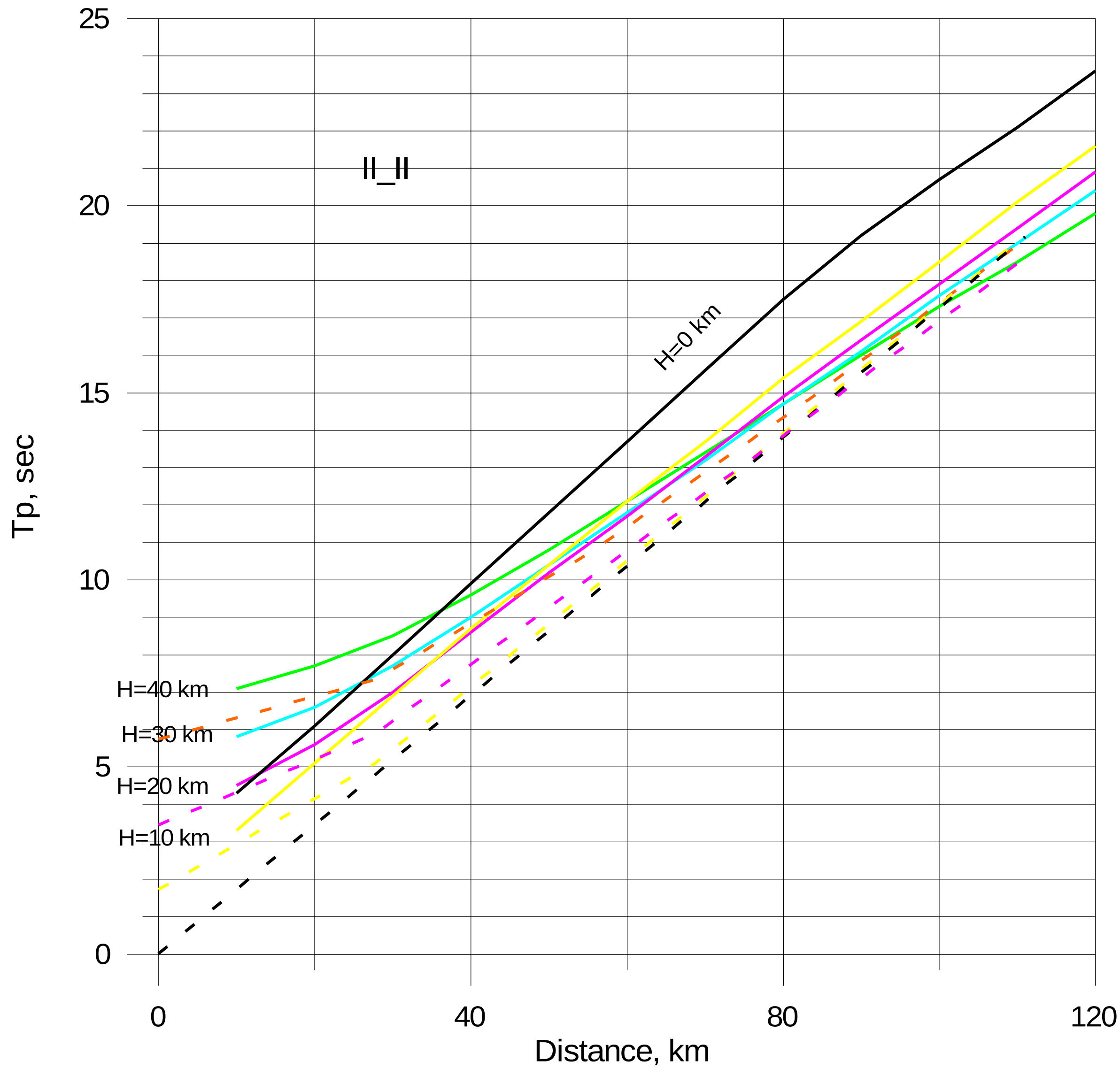


Figure 12. Comparison of travel-time curves for the region II per Pivovarova&Slavina, 1985, (continuous lines) and the IASPEI-91 Pg travel-time curves (dashed lines) for different event's depths: black lines – 0 km; yellow lines – 10 km; violet lines – 20 km; blue line – 30 km; green line – 40 km; orange line – 35 km (IASPEI-91).

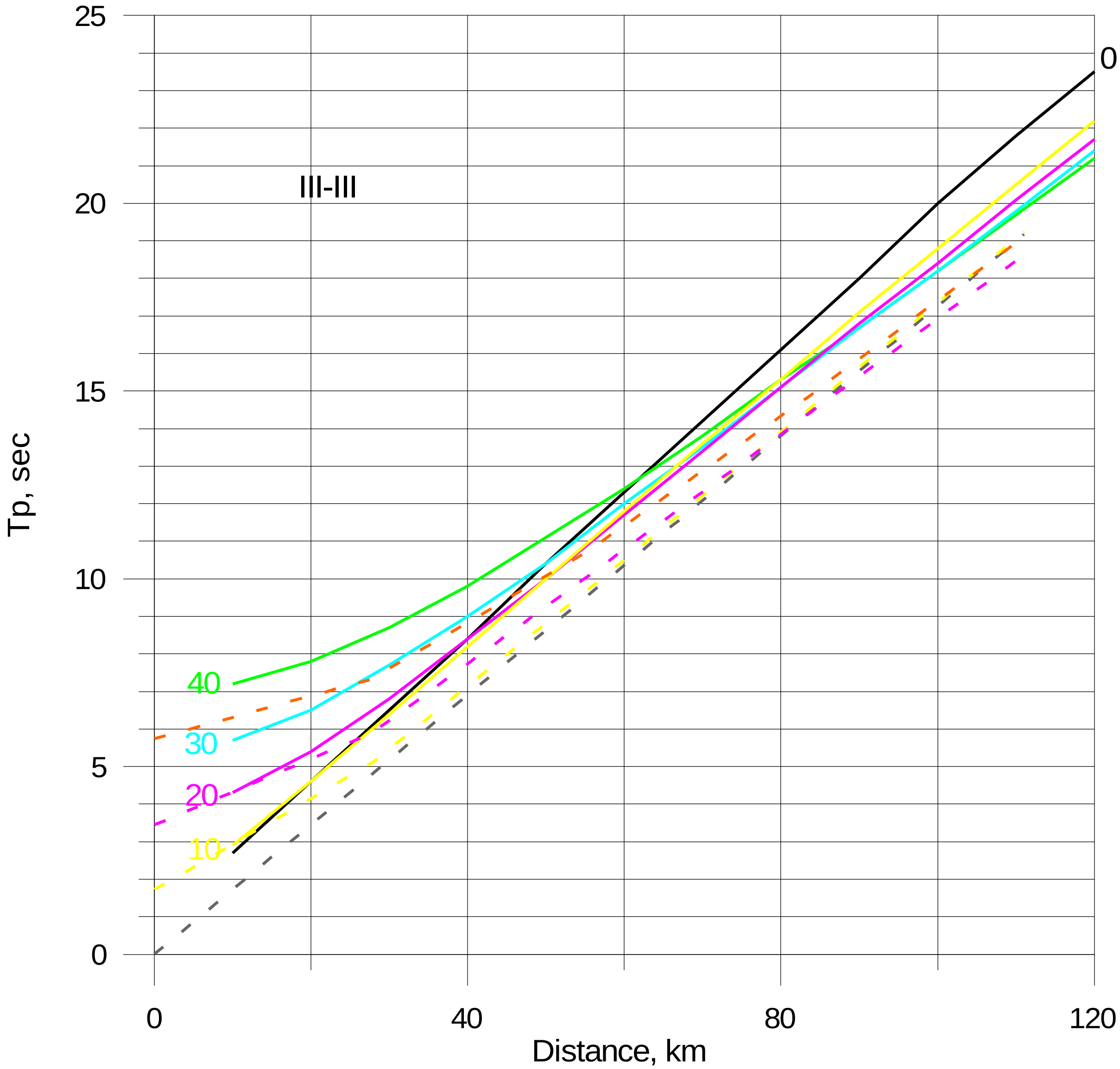


Figure 13. Comparison of travel-time curves for the region III per Pivovarova&Slavina, 1985, (continuous lines) and the IASPEI-91 Pg travel-time curves (dashed lines) for different event's depths: black lines – 0 km; yellow lines – 10 km; violet lines – 20 km; blue line – 30 km; green line – 40 km; orange line – 35 km (IASPEI-91).

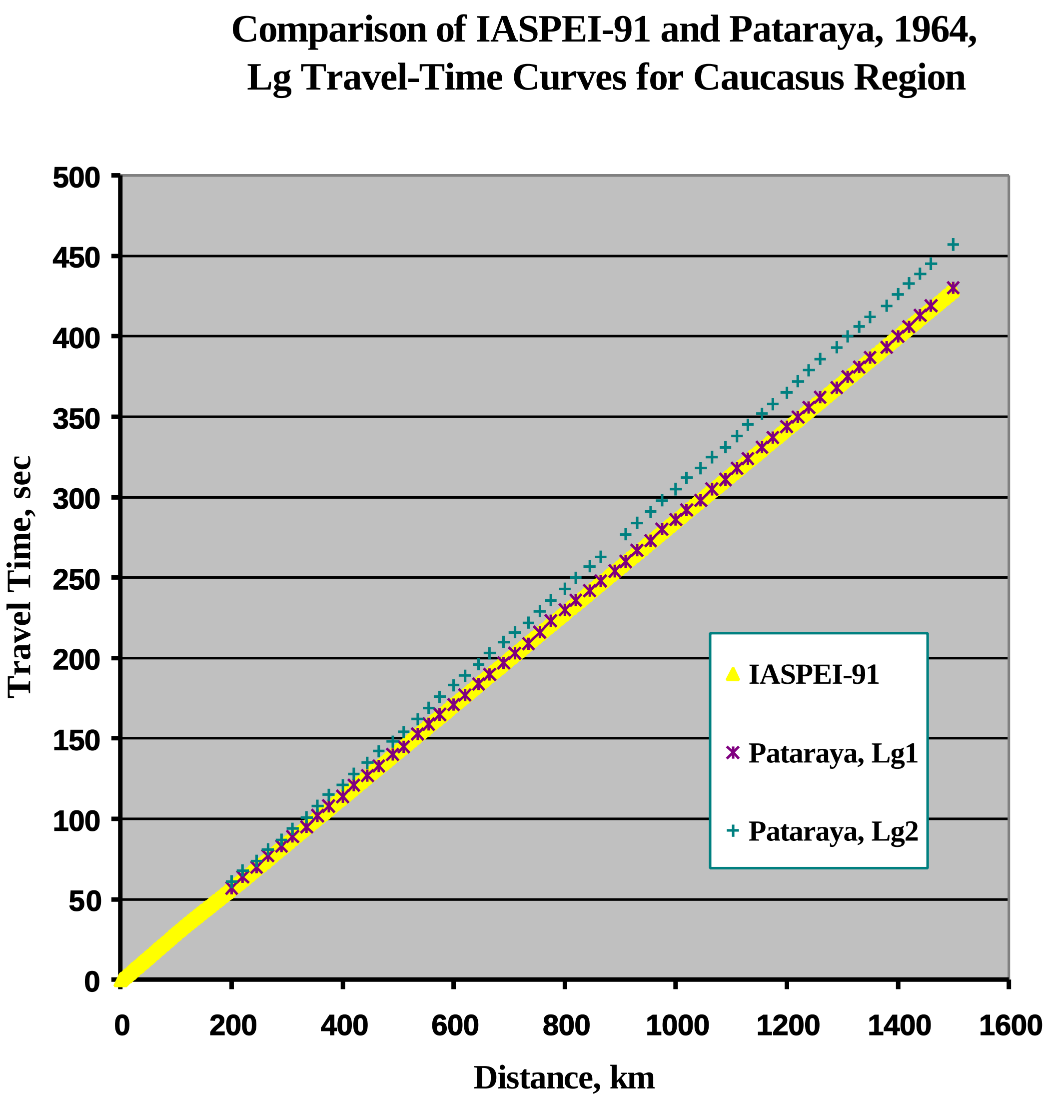


Figure 14. Comparison of Lg Travel-Time Curves.

TABLES

Table1. Parameters of Selected Candidate Reference Events for Northern Caucasus Region

No.						
1.	1994 01 27	4.2	16 04 48.3	44.03	42.95	Northwestern Caucasus
2.	1994 02 11	5.3	17 40 08.3	42.53	43.93	Northwestern Caucasus
3.	1994 06 05	5.5	01 20 00.7	42.47	43.32	Northwestern Caucasus
4.	1994 08 23	4.9	10 45 18.5	43.40	44.44	Northwestern Caucasus
5.	1994 09 19	4.7	15 23 40.4	42.69	43.48	Northwestern Caucasus
6.	1994 09 21	5.2	08 53 24.2	42.68	43.46	Northwestern Caucasus
7.	1994 10 14	4.1	17 12 46.8	44.18	42.58	Northwestern Caucasus
8.	1994 10 18	3.7	21 18 35.8	44.18	42.57	Northwestern Caucasus
9.	1994 12 12	4.6	13 14 05.7	42.64	43.44	Northwestern Caucasus
10.	1995 01 15	4.7	07 13 22.0	43.28	47.39	Eastern Caucasus
11.	1995 08 04	4.9	13 29 32.1	43.31	43.62	Northwestern Caucasus
12.	1995 08 19	5.1	04 21 14.8	43.23	45.88	Eastern Caucasus
13.	1995 09 25	5.6	12 02 41.1	44.45	41.33	Northwestern Caucasus
14.	1996 02 17	4.1	05 42 43.4	43.62	43.17	Northwestern Caucasus
15.	1996 05 31	4.5	09 25 41.9	43.00	47.10	Eastern Caucasus
16.	1996 06 06	4.8	05 23 31.9	42.60	43.50	Northwestern Caucasus
17.	1996 07 06	4.0	20 17 24.1	42.25	46.75	Eastern Caucasus
18.	1997 02 06	4.7	16 03 43.0	42.98	47.03	Eastern Caucasus
19.	1997 04 03	4.2	22 20 50.1	44.60	42.10	Northwestern Caucasus
20.	1997 07 12	4.1	22 02 07.2	42.83	46.15	Eastern Caucasus
21.	1998 06 08	5.1	09 55 17.7	42.42	43.60	Northwestern Caucasus
22.	1998 01 21	4.5	05 55 26.5	43.01	47.21	Eastern Caucasus
23.	1998 02 04	4.5	23 30 55.5	43.00	47.65	Eastern Caucasus
24.	1998 02 11	4.6	18 09 18.2	42.81	46.44	Eastern Caucasus
25.	1998 06 15	4.3	20 18 14.8	44.02	42.97	Northwestern Caucasus
26.	1998 08 14	3.7	16 38 46.1	44.02	42.73	Northwestern Caucasus
27.	1998 09 20	4.5	19 47 17.4	42.46	46.34	Eastern Caucasus
28.	1998 10 08	4.5	21 18 40.4	44.03	44.19	Northwestern Caucasus
29.	1998 12 29	3.6	17 40 22.1	43.31	41.53	Northwestern Caucasus
30.	1999 01 31	5.1	05 07 10.7	43.09	46.87	Eastern Caucasus
31.	1999 01 31	4.5	08 16 00.9	43.11	47.02	Eastern Caucasus
32.	1999 01 31	4.2	08 37 25.7	43.09	46.96	Eastern Caucasus
33.	1999 01 31	4.3	11 40 08.8	43.11	47.02	Eastern Caucasus
34.	1999 01 31	4.2	12 06 08.2	43.15	47.02	Eastern Caucasus
35.	1999 02 01	4.3	03 43 46.4	43.11	46.96	Eastern Caucasus
36.	1999 02 01	4.7	14 25 53.5	43.08	47.00	Eastern Caucasus
37.	1999 02 01	4.7	23 57 49.9	43.11	46.96	Eastern Caucasus
38.	1999 02 04	4.8	10 36 15.5	42.62	45.87	Eastern Caucasus
39.	1999 02 21	5.6	18 14 30.1	43.16	47.00	Eastern Caucasus
40.	1999 02 22	4.7	13 33 17.1	43.17	47.00	Eastern Caucasus
41.	1999 02 23	4.6	19 17 57.3	43.16	46.94	Eastern Caucasus
42.	1999 02 24	4.6	05 49 29.7	43.42	47.21	Eastern Caucasus
43.	1999 03 13	4.7	20 22 16.0	43.09	46.91	Eastern Caucasus
44.	1999 03 20	4.4	17 49 43.6	43.10	46.94	Eastern Caucasus
45.	1999 04 13	4.6	23 44 51.0	43.09	46.93	Eastern Caucasus
46.	1999 04 15	4.9	11 16 11.3	43.14	46.95	Eastern Caucasus
47.	1999 05 22	4.6	14 19 18.2	42.54	43.01	Northwestern Caucasus
48.	1999 06 06	4.8	11 34 34.5	43.14	46.95	Eastern Caucasus

No.						
49.	1999 06 26	5.0	10 27 43.0	43.26	45.88	Eastern Caucasus
50.	1999 08 10	4.6	18 21 23.8	43.17	46.99	Eastern Caucasus
51.	1999 08 28	3.4	14 39 44.3	44.08	42.77	Northwestern Caucasus
52.	1999 09 19	5.4	16 46 56.0	43.12	46.92	Eastern Caucasus
53.	1999 10 19	4.8	18 18 45.3	44.68	42.67	Northwestern Caucasus
54.	1999 12 03	4.0	13 12 50.4	44.62	42.42	Eastern Caucasus
55.	1999 12 09	3.7	19 40 59.9	44.03	42.98	Northwestern Caucasus
56.	2000 01 28	4.5	23 27 09.8	43.03	47.00	Eastern Caucasus
57.	2000 03 19	4.2	07 20 35.0	43.49	41.31	Northwestern Caucasus
58.	2000 04 07	3.9	02 46 48.5	43.05	46.94	Eastern Caucasus
59.	2000 04 12	4.9	00 01 28.3	43.12	46.94	Eastern Caucasus
60.	2000 04 15	4.8	07 15 19.7	43.09	47.02	Eastern Caucasus
61.	2000 06 30	4.5	17 05 29.9	42.86	46.05	Eastern Caucasus

Table 2. Typical Velocity Earth's Crust Models for Caucasus

No.	Region Name	Depth, km	Thickness, km	Vp (top), km/sec	Vp (bottom), km/sec
1	Karpinsky Swell	0	2	2.3	2.3
		2	13	5.4	5.4
		15	5	5.6	5.9
		20	11	6.3	6.5
		31	11	6.8	6.9
		42	13	8.3	8.4
		55	15	8.0	8.1
		70	-	8.4	-
2	Terek-Caspian Depression	0	6	2.7	3.6
		6	7	5.3	5.8
		13	7	6.0	6.1
		20	11	6.4	6.6
		31	11	7.0	7.1
		42	16	8.1	8.2
		58	16	7.9	8.0
		74	-	8.3	-
3	Greater Caucasus Central Block	0	2	2.0	3.0
		2	8	5.6	6.2
		10	12	5.8	5.8
		22	5	6.4	6.4
		27	11	6.6	6.6
		38	12	6.9	7.0
		50	-	8.1	-
4	Greater Caucasus Eastern Block	0	2	2.4	3.0
		2	8	5.5	5.6
		10	4	6.0	6.0
		14	9	5.8	5.8
		23	10	6.5	6.5
		33	21	6.8	6.8
		54	5	8.3	8.3
		59	7	7.8	7.8
		66	-	8.5	-
5	Greater Caucasus Eastern Block (close to Caspian Sea)	0	0.5	2.4	3.5
		0.5	8.5	3.5	5.4
		9	9	6.2	6.4
		18	7	6.0	6.0
		25	12	6.8	6.8
		37	18	7.4	7.4
		55	-	8.1	-

No.	Region Name	Depth, km	Thickness, km	Vp (top), km/sec	Vp (bottom), km/sec
6	Rion Basin	0	1	2.4	2.5
		1	3	3.8	4.2
		4	7	6.0	6.3
		11	11	6.7	6.7
		22	12	7.0	7.0
		34	7	7.3	7.3
		41	7	7.5	7.5
		48	-	8.2	-
7	Dzirul Massif	0	0.3	3.0	3.0
		0.3	~14	5.8	6.3
		14	8	6.7	6.7
		22	17	7.3	7.3
		39	11	7.5	7.5
		50	-	8.3	-
9	Middle-Kura Basin (Western Part)	0	15	2.0	5.5
		15	2	6.5	6.8
		17	28	7.8	7.9
		45	3	7.5	7.5
		48	-	8.0	-
10	Middle-Kura Basin (Central Part)	0	6	2.1	5.0
		6	10	6.3	6.6
		16	13	7.0	7.0
		29	12	6.5	6.5
		41	-	8.1	-
11	Lower-Kura Basin (Saatlinsky Section)	0	7	1.8	4.7
		7	5	6.7	6.8
		12	11	7.0	7.1
		23	19	7.4	7.4
		42	-	8.0	-
14	Sevan Ophilite Belt	0	5	4.0	4.2
		5	8	6.7	7.1
		13	7	6.6	6.6
		20	4	7.0	7.0
		24	22	7.2	7.2
		46	-	8.3	-
15	Nakhichevan Basin	0	2	3.1	3.1
		2	3	5.2	5.3
		5	11	6.3	6.2
		16	9	6.4	6.5
		25	5	7.0	7.0
		30	16	7.2	7.2
		46	-	8.0	-

No.	Region Name	Depth, km	Thickness, km	Vp (top), km/sec	Vp (bottom), km/sec
16	**Erevan Depression**	**0**	**8**	**5.4**	**5.8**
		8	**5**	**5.3**	**5.4**
		13	**8**	**7.3**	**7.4**
		21	**7**	**6.7**	**6.8**
		28	**15**	**7.6**	**7.7**
		43	**7**	**5.1**	**5.2**
		50	**-**	**8.1**	**-**
17	**Urtssk Uplift (I)**	**0**	**5**	**4.4**	**4.8**
		5	**31**	**6.0**	**6.5**
		36	**9**	**5.3**	**5.4**
		45	**-**	**7.7**	**-**
18	**Urtssk Uplift (II)**	**0**	**5**	**4.4**	**4.8**
		5	**7**	**6.0**	**6.1**
		12	**24**	**6.3**	**6.5**
		36	**9**	**5.3**	**5.4**
		45	**-**	**7.7**	**-**
19	**Razdan Terrace**	**0**	**5**	**4.4**	**4.8**
		5	**10**	**6.0**	**6.2**
		15	**13**	**6.7**	**6.8**
		28	**14**	**7.6**	**7.7**
		42	**11**	**5.1**	**5.2**
		53	**-**	**8.0**	**-**
22	**Maralin Uplift**	**0**	**8**	**5.4**	**5.8**
		8	**5**	**5.3**	**5.4**
		13	**8**	**7.3**	**7.4**
		21	**20**	**6.8**	**6.9**
		41	**-**	**7.8**	**-**

Table 3. Average Velocities for Different Depths of Events within the Dagestan Wedge

h, km	Vp, km/sec	Vs, km/sec	Vp/Vs
3	4.24	2.34	1.81
6	4.40	2.47	1.78
9	4.60	2.62	1.76
12	4.90	2.83	1.73
15	5.10	2.97	1.72
18	5.30	3.10	1.71
21	5.60	3.33	1.68
24	5.80	3.47	1.67

Note: **h – depth of layer's bottom; Vp – P-wave velocity; Vs - S-wave velocity.**

Table 4. Velocity Models for Northern Caucasus Region

Zone							
A (Murusidze, 1976)		B (Fyatelson, 1982)		C (Krylov, 1987)		D (Krylov, 1987)	
h, km	Vp, km/sec	h, km	Vp, km/sec	h, km	Vp, km/sec	h, km	Vp, km/sec
0.0	4.0	0.0	3.2	0.0	3.2	0.0	4.0
2.0	5.7	1.0	5.9	5.5	5.3	10.0	6.0
19.0	6.5	15.0	6.0	13.0	6.0	14.0	5.8
41.0	8.0	24.0	6.4	22.0	6.5	23.0	6.5
		29.0	7.0	32.0	7.0	33.0	6.8
		44.0	8.1	43.0	8.1	53.0	8.3

Note: **h – depth of layer's top; Vp – P-wave velocity.**

Table 5.1. Selected Reference Events for Northern Caucasus Region (at 90% and 95% confidence

No.	Date, yy/mm/dd	Origin Time, hh:mm:ss	Lat., Deg.	Long., Deg.	Depth, km	Smaj, km	Ndef	Ndef <250	Gap, deg.	Maximum Primary Gap, deg.	Maxim Second Gap, d
						Northern Caucasus					
1	94/01/27	16:04:48.37	44.035	42.946	9.4	4.3	22	20	108	108	152
2	94/09/21	08:53:19.73	42.479	43.484	6.3	4.3	24	22	99	99	152
3	96/06/06	05:23:29.08	42.524	43.529	11.2	4.1	26	26	66	66	121
4	98/06/15	20:18:14.61	44.016	42.973	9.3	3.8	20	20	72	72	118
5	99/09/12	19:40:59.72	44.031	42.995	8.9	4.0	18	18	86	86	122
						Eastern Caucasus					
1	98/09/20	19:47:16.24	42.432	46.287	0.4	3.7	40	35	99	99	143

Table 5.2. Candidate Events in Northern Caucasus Region (close to the criteria discrimination

No.	Date, yy/mm/dd	Origin Time, hh:mm:ss	Lat., Deg.	Long., Deg.	Depth, km	Smaj, km	Ndef	Ndef <250	Gap, deg.	Maximum Primary Gap, deg.	Maxim Second Gap, d
						Northern Caucasus					
1	94/02/11	17:40:05.92	42.427	43.872	5.2	9.4	27	25	123	123	137
2	94/08/23	10:45:18.63	43.383	44.463	5.0	5.5	21	21	142	142	151
3	94/10/14	17:12:46.70	44.176	42.580	3.5	4.7	17	17	90	90	166
4	98/08/14	16:38:46.53	44.015	42.747	10.1	6.0	19	19	125	125	208
						Eastern Caucasus					
1	98/02/11	18:09:18.07	42.830	46.425	1.4	5.4	28	25	148	148	171

Table 5.3. Other Studied Events in Northern Caucasus Region

No.	Date, yy/mm/dd	Origin Time, hh:mm:ss	Lat., Deg.	Long., Deg.	Depth, km	Smaj, km	Ndef	Ndef <250	Gap, deg.	Maximum Primary Gap, deg.	Maxim Second Gap, d
Northern Caucasus											
1	94/06/05	01:19:58.67	42.454	43.438	8.0	5.5	25	23	149	149	196
2	94/12/12	13:14:03.38	42.522	43.525	8.2	5.3	19	17	137	137	210
3	98/10/08	21:18:43.63	44.019	44.165	23.6	6.7	35	24	154	154	226
4	98/12/29	17:40:19.81	43.357	41.532	4.5	5.1	32	28	131	131	242
5	99/10/19	18:18:44.78	44.713	42.640	7.6	5.7	26	24	153	198	309
Eastern Caucasus											
1	96/05/31	09:25:44.09	43.033	47.039	19.9	6.8	20	15	184	184	233
2	97/07/12	22:02:06.50	42.771	46.013	1.3	6.6	20	18	142	145	287
3	98/01/21	05:55:26.83	43.021	47.183	7.5	6.8	25	23	187	187	194